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THESIS

The Use of Process Control Instruments as an Aid To Management

by

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INTRODUCTION:

It is quite generally recognized that the goal of our free enterprise system is to provide the highest standard of living for the greatest number. To make this a reality we must maintain a high rate of production of essential commodities, & prices must be low enough to enable the ultimate consumer to satisfy his needs. As every manufacturer knows, acceptable prices cannot be achieved without close attention to all the elements entering into processing and distribution costs. Because of economic pressure from all sides, it is becoming increasingly difficult to maintain these acceptable prices.

In the so called process industries, not much can be done to reduce the cost of basic raw materials. When the problem is analyzed as a whole, the best opportunities for effecting cost reductions lie in two directions. First, the productivity of manpower and processing must be increased. Secondly, raw materials must be better utilized to produce a better end product with less waste and reprocessing.

It is in relation to both of these factors that industrial instrumentation offers tangible benefits. During the past twenty years, instrumentation has grown from an art using relatively crude implements to a science employing the latest control instruments available. It is generally conceeded that the production of such com-

modities as high octane gasoline, synthetic rubber, dehydrated foods, plastics, and synthetic textile fibers would not have been possible without the amazingly efficient control of industrial instruments.

This paper attempts to approach the subject of instrumentation from a management rather than from a technical or engineering point of view. The chemical and instrument societies have directed their deliberations, to a great extent, to instrument and chemical engineers with emphasis upon theory of control, mathematical analysis of processes, control valve characteristics, application engineering, and other rather technical aspects of the subject. A typical symposium on process control appeared in the May 1943 issue of 'Chemical & Metalurgical Engineering'. This series of articles dealt with automatic control theory, control valve characteristics, and process variables.

Several text books have appeared on the subject but they have again dealt with a technical approach to measurement and control. Two such books are T.J. Rhodes' Industrial Instruments for Measurement and Control[1] which was intended as a textbook for the formal study of the subject of instruments and automatic control in engineering schools, and D.P. Eckman's Principles of Process Control[2] which was primarily devoted to the description and explanation of fundamental principles of control.

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(1) McGraw Hill Book Co. 1942
(2) John Wiley & Sons 1945

From time to time articles concerning economic and technical aspects of instrumentation appear in the trade magazines. There is a trend among instrument manufacturers to publish case studies of industrial installation showing new applications, and developments of instruments. Two manafacturers who have done this are The Brown Instrument Company which publishes Instrumentation and The Taylor Instrument Company which publishes Taylor Technology. The bibliography contains many of these articles and the titles of the other trade publications.

In this study the approach to the subject is from a different point of view. There is an attempt to show the areas of management that are affected by process instruments, variables and control; and how these instruments can aid the process industries in producing more and better products at ever lower costs.

It is believed that at the present time a factor that can lower production costs, increase quality, make new processes possible, provide information for better control of existing processes, and increase production without increasing capital investment appreciably should be well worth investigating.

A recent market survey (1) seems to bear out this reasoning. Some comments of men interviewed concerning instruments are as follows:

(1) Industry & Power Market Survey McClusky Publishing Co. St. Joseph, Michigan 1949

1. Plant engineers believe in instruments. They would prefer complete automatic controls, with numerous indicating and recording meters to measure every variable and indicate every condition. They have difficulty selling such a program to "management," and need help in doing it.

2. One difficulty in "selling" instruments to management is the inablity of the engineers to determine exactly what cost reductions or savings might be affected because they have no previous records with which to compare data.

3. Instrument manufacturers could help by providing many case studies to show the value and application of instruments or controls in terms of reduced costs, fuel savings, reduction or prevention of "outages" lengthened life of equipment, reduction of rejected parts, and improved quality.

CHAPTER I MANAGEMENT-ITS FUNCTIONS & OBJECTIVES

The functions and tasks of the present day process industries managements have become very important factors in our economy. The process industries which include chemical and allied industries accounted for approximately half of the total sales dollars of all manufacturing industries in this country in 1945.(1)

Management has the job of organizing and keeping in balance the three parties that comprise our economy- consumer, worker, and investor. It must achieve maximum productivity from this three party system if we are to keep and strengthen our present economic system. Our industries are entering a period where management must answer the question, "How can future profit margins be maintained in the face of rising costs and increased resistance by consumers to high selling prices?"

The major functions of management pertaining to the process industries may be listed as follows:

1. Research
2. Development
3. Production
4. Purchasing
5. Sales
6. Finance or Capital Investment

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(1) Chaplin Tyler; Chemical Engineering Economics, McGraw Hill Book Co. 1948 p. 7

The use of control instruments can aid management in performing these functions by increasing individual effectiveness, eliminating waste, reducing costs and aiding in effective planning. Control instruments are important factors in maintaining profit margins in the face of rising costs and consumer resistance to high selling prices.

Research:

No manufacturing organization , no matter what the size, can afford to neglect or exclude research from its corporate activities. Research should be looked upon as a form of insurance, the purpose of which is to protect the future as well as the current business of the organization.

Dr. Charles Kettering formerly of General Motors expressed research as the finding out what we are going to do when we cannot continue doing what we are now doing.

It may further be defined as a systematic search investigation, experimentation, and examination of the known to determine the unknown.

Research may be directed towards the attainment of any or all of the following objectives: (1)

(1) A. Gregg Noble, ' Small industry must plan now to survive postwar changes.' Chemical Engineering Dec. 1944 p. 120

1. Reduction of production costs
2. Reduction in processing time
3. Increasing the yield
4. Increasing the life of the equipment
5. Providing cheaper raw materials
6. Development of new products
7. Development of new outlets for present products

(2)

To the above objectives may be added:

8. Anticipation and prevention of trouble
9. Cure of existing troubles
10. Improvement of quality of existing materials
11. Bring about standardization
12. Gather technical information leading to a better understanding of a product.

In the chemical field emphasis on research has always been relatively important. Many branches of the industry were actually created by reaearch and in general the industry recognizes that research is essential to progress.

One of the greatest research projects ever undertaken was the goverment's $1,000,000,000 program for atomic energy. Automatic instruments made the processing of radio active elements possible in large enough quantities to be of value.

In the plastics field, automatic instruments have made many polymerization reactions possible. Instrumentation has accounted for large scale production of polystyrene and poly vinyl chloride.

It is estimated that between two and three percent of total sales income is spent by the chemical

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(2) Chaplin Tyler, op. cit., pp. 17

industries on research, wheras all manufacturing averages only one-fifth as much. In 1946 approximately $700,000,000 was spent for industrial research and the chemical and allied industry accounted for about 25% of this total.

Management of research is vital for success. The expenditure of large sums of money is no guarantee of success. The money must be spent efficiently. The ideas must be sifted and evaluated in the light of two basic criteria, namely 1. Will it work? and 2. Will it pay? One has only to read Chester H. Pennings's article 'Tremendous Trifles'(1) to realize the tremendous sums of money that have been wasted and are being wasted on ideas which were not properly appraised, were misjudged, or were applied without being judged at all.

The following essential elements must be prepared and evaluated in order to prevent wastage of capital:

1. Raw materials including fuel and water, their supply and cost.

2. A satisfactory process with costs worked out.

3. Market for product and by-products.

4. Data on products and by-products.

5. Satisfactory methods for disposal of waste products and fumes.

6. Patent situation and advantages which the corporation may have over its prospective competitors.

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(1) C. H. Penning, ' Tremendous Trifles', Chemical Engineering Febuary 1939 pp 76-79

Developments:

Between the discoveries of the research laboratory and the realization of commericial operation lies the field of process development.

Process development is extremely important in the development of new processes because it tends to lessen the risk by extending the period of preliminary study. During this period of time process variables can be studied and instruments designed or applied to control the reactions.

Process evolution may be divided into five stages:

1. Beaker or laboratory
2. Small sized model
3. Large sized unit
4. Semicommercial pilot plant
5. Commercial plant

The first three stages require much time and energy but, comparitively little money to be expended. The semicommercial pilot plant is probably the most important step in the process. It is essential whenever the project covers a distinctly new chemical or a new method of manufacturing.

The functions of pilot plants are as follows: (1)

(1) C. O. Brown, 'Equipment and Design', Industrial & Engineering Chemistry, August 1948, pp 64A

1. To handle larger flows than are practical in the laboratory in order to determine correct ratios, flows, and weights approximating commerical operation.
2. To allow a better study of corrosion effects.
3. To determine efficiencies of operation.
4. To prove correct instrumentation.
5. To devise and test control instruments.
6. To gather data on the effect of lag in the control devices and to study these effects on quality and yield of product.
7. To develop engineering data such as pressure drops at various capacities; power requirements and film coefficients.
8. To prove suitability of available raw materials.
9. To study the effects of trace impurities found in the raw materials.
10. To obtain sufficient finished product to assure samples for sales or in further synthesis.

It is interesting to note that in many cases as much as 50% of the total investment in a pilot plant is in instruments and controls.

Production:

Production management is responsible for the actual manufacturing of the product. This includes quantity, quality, and cost of production.

Process control instruments have played an important role in increasing the productive capacity of the chemical process industries.

The following table shows the production of various chemicals that have relied to a great extent upon automatic process control instruments.

TABLE I PRODUCTION OF VARIOUS CHEMICALS (1)

(1) Industrial& Engineering Chemistry, June 1948,pp 949-999

TABLE I PRODUCTION OF VARIOUS CHEMICALS

PRODUCT	PRODUCTION					
	1939	1940	1942	1944	1945	1947
Sulfuric Acid 1000s. tons	2,674		4,839	6,005		7,270
Styrene 1000 tons	0.417		4.84	175	203	
Formaldehyde 1000 lbs.		18,100	34,750		50,960	51,380
100 Octane Gas bbls. per day			45,000		600,000	

Without automatic instrument control many modern processes would be practically impossible. The change to continuous operation, brought on by economic as well as increased demand for products, has eliminated time as an independant variable. Each step in the process must be exactly correct at all times to achieve this increased production. It is therefore no longer possible for the operator to correct errors by introducing more time in certain phases of the operation and consequently the use of control instruments has almost eliminated the human errors in production.

In a war economy, production problems are quite different from those of a competitive economy where cost is an important factor. Management must apply certain factors in obtaining control of production and costs. Proper planning of production is essential to efficient, economical, utilization of plant and personnel.

Cost savings through instrumentation can appear in several ways: (1)

1. Reduction in labor costs
2. Reduction in capital
3. Reduction of spoilage or rejected material
4. Increased production in the same equipment

Labor Costs

Instruments save direct manual labor. The trend today is toward a smaller number of better paid, higher skilled, more intelligent process operators. For a cost comparison and discussion see Chapter IV, Cost of operating labor versus instruments.

Reduction of Spoiled or Rejected Material

Quality Control includes reduction of spoilage and production of a uniform product, and can be brought about by process control instruments in the following ways:

1. Application of exacting control held to small tolerances aids in the production of a uniform product.
2. Elimination of waste in raw materials and finished products due to control of process variables.

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(1) C. S. Comstock, 'How good instrumentation can save dollars' Part I Chemical Industries Dec 1948, p 95

Increased Production in the same equipment

Automatic instruments give a more uniform flow and eliminate to some extent surges in the line. This makes operation of equipment close to maximum capacity a reality. Another way of achieving increased production in the same equipment is to reduce the factor of safety which can be justified by confidence in the control instruments.

FINANCE and CAPITAL INVESTMENT

Finance may be interpreted in many ways depending upon the viewpoint. Bankers may regard it from the point of investment. How can capital be obtained and under what terms? Accountants on the other hand may look at finance from the bookkeeping viewpoint. What is the proper rate of depreciation and obsolescence? How is adequate working capital determined? Another viewpoint deals with plant investment and the means of affecting economies in the operation of plant units.

Management is concerned with all of these views and at the present time the factors of plant expansion and economies in operation of plant units are very pertinent.

Over 800 million dollars of construction contracts were either issued or work proposed in the chemical industries in 1948.(1) Total plant post war

(1) Chemical Engineering December 1948

expansion for the process industries through 1949 will be in the vicinity of 6 billion dollars.

The importance of instruments in this expansion and construction can be seen from the following table giving installed costs of instruments as a percentage of total equipment costs.

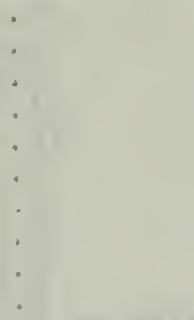
(1)

TABLE II INSTALLED COSTS OF INSTRUMENTS AS PERCENTAGES OF TOTAL PROCESS EQUIPMENT COSTS

Industry	% of Cost
Ethylene Plant	4.0
Synthetic Ammonia	3.2
Viscose Rayon	2.9
Styrene Plants	4.0
Pharmaceuticals	15.0
Thermofor Cracking	3.4
Hydrofluoric Acid Alkylation	5,7
Gas Recovery Units	4.9
Plastics & Agricult. Chem.	9.7
Pulp Mills	3.0

(1) Considine, D.M. 'Estimation of Instrument costs' Chemical Engineering July 1947

The effective use of instrumentation constitutes a major factor in reducing plant investment. The production of styrene, used in producing synthetic rubber and plastics, takes place in two basic steps, namely:1.The alkylation of benzene with ethylene to produce ethylbenzene, and 2. dehydrogenation of purified ethylbenzene to give styrene. There is, however, another step before a 99.7% pure product is obtained. Since the product of the dehydrogenation unit contains about 37% styrene, it must be further purified and concentrated in a styrene finishing unit.



These three units, which as a group take ethylene and benzene as raw materials and produce 99.7% pure styrene as a product, are collectively known as a train. Styrene plants are usually constructed of 3 or 4 such trains.

In the Monsanto Texas City Styrene plant, instruments have eliminated the necessity of storage capacity tanks between dehydrogenation towers. The cost of the necessary instruments is far less than the cost of the necessary tanks. It has the advantage of keeping the equipment operating at peak efficiency thus providing greater capacity and permitting a reduction in its size. Instruments can detect the first deviation from the control point and automatic control devices can make the necessary correction immediately. Any variation from the desired rate of operation is thus held to a minimum. Experience indicates that the addition of instruments may increase capacities from 10 to 20 percent. Since the average investment due to instrumentation is approximately 5%, a significant decrease in the investment per unit capacity can thus be obtained.

CHAPTER II INSTRUMENTATION PROCESS VARIABLES

The process industries have developed around the measurement and control of process variables. In the early days of these industries, measurement was often intuitive and control was manual. The demand for better yields, quality and ever lower production costs has forced these industries to turn to industrial instruments for measuring and control.

Industrial instruments can exert far higher measuring accuracy than is possible by the intuitive method. In fact, practically every desirable characteristic with the exception of judgement can be built into them.

In determining how a process shall be controlled, it is important to isolate all the process variables that will be encountered, determine which are independant variables and which will influence the process results enough to require control.

Process variables may be classified in the following manner:

I Energy Variables
1. Temperature
2. Pressure or vacuum

II Quantity and Rate Variables
1. Fluid flow rate
2. Liquid level
3. Weight
4. Thickness
5. Speed of machinery

III Composition
1. Density and specific gravity
2. Viscosity and consistency
3. pH or hydrogen ion concentration
4. Electrical conductivity
5. Thermal conductivity
6. Caloric value
7. Explosibility and flammability
8. Humidity
9. Color, turbidity, opacity
10. Moisture content
11. Compsition itself

IV Electrical Variables
1. Potential
2. Current
3. Power
4. Resistance

To cover all of these variables would be beyond the scope of this paper. Therefore the discussion is limited to considerations of temperature, pressure, flow, and liquid level because the largest number of industrial instruments are confined to the measurement and control of these four variables.

Temperature

Nearly all chemical processes involve the evolution or absorption of heat. It is not surprising, therefore, that temperature measurements rank first among all measurements made in the chemical processing industries.

Temperature along with the specific heat of the material is a measure of the amount of heat energy contained in the material. It cannot be measured directly but is dependant upon the properties of the material or from those of another material in thermal equilibrium with it. Temperature may be inferred from the expansion and contraction of solids, liquids, or gases; from the vapor

tension of a liquid; from the electrical resistance of materials, usually metals; from the thermoelectric potential produced by dissimilar metals in contact; from the intensity of total radiation, or a particular band of wavelengths of radiation given off by a hot body; and from a change of state of solids, liquids, or gases.

Measurements of the expansion of liquids, and gases, vapor tension of a liquid and the thermoelectric effects of dissimilar metals in contact, represent the embodiments of temperature measurements that are used most extensively in industrial control instruments.

All recording thermometers are made up of five distinct related parts which serve to translate a change in temperature in the medium being measured into a continuous record of that change on a circular time-temperature chart. These five parts are:

1. A sensitive pressure bulb that is emmersed in the medium to be measured and contains the actuating pressure medium. In an electrical circuit, the actuating medium is the current produced (thermoelectric effect) by two dissimilar metals in contact.

2. A capilary tube connecting the bulb to the recorder.

3. An activating mechanism in the recorder to respond to changes in pressure.

4. A linkage to multiply the movement of the actuating mechanism and draw a line on the recording chart.

5. A chart mechanism to hold a recording chart and revolve it at a fixed speed.

Figure 1 represents the essential parts of a recording thermometer.

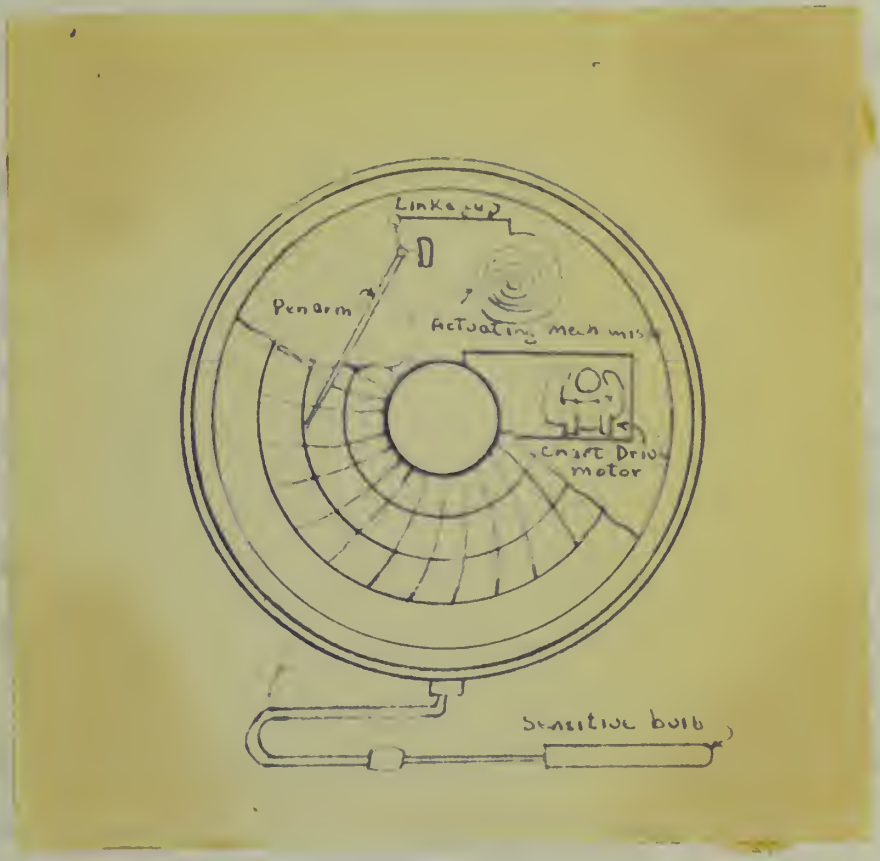


Fig. 1 Recording Thermometer

Gas, liquid, and vapor filled systems:

The use of a gas, liquid, or vapor, that will produce a pressure differential due to changes in temperatures is extensively used in process instruments. These systems are used in processes that have a temperature range between -50 ^{o}F and 1000 ^{o}F.

These systems are used in the canning, textile and paper industries because they are relatively inex-

pensive and have operating temperatures utilized in processing foods, textiles, and paper.

In the canning industry these systems are specifically used in hot water blanches, lye peelers, exhaust boxes, retorts, continuous open cookers, pasteurizers, and cooling canal operations.

At the P.J. Ritter Co., Budgeton, New Jersey, improved control systems especially temperature controllers have increased production 20%[1] and have improved quality, appearance and flavor of canned fruits and vegetables.

Modern textile mills use these same actuating mediums in controlling size temperatures, bleaching, slashing, kier boiling, dyeing and drying temperatures.

At the Dan River mills temperature control has enabled the mills to produce uniform products, cut steam and water costs, and save on operating labor. At the Kent Manufacturing Company in Clifton Heights, Pa. process control instruments have aided in maintaining color uniformity in the dyehouse, increasing production 100%[2] reducing water consumption by 50%, time of scouring by 40%, and increasing strength of the textile fibers by 15%.

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(1) "Production of canned foods increased by the application of automatic controls to retorts." Taylor Technology Winter 1948 Issue

(2) "Everything Under Control" Textile World Aug.1938 pp 54-55

In the paper industry control systems are widely used in steam generation, pulp digesting, acid preparation, caustic preparation, black liquor recovery, bleaching, drying, coating and sizing.

Temperature controllers are helping improve manufacturing techniques, lower material, fuel, and labor costs, and improve the quality of paper products.

Thermoelectric Activating Mechanisms

The phenomenon that an electromotive force was created when two dissimilar metals were joined and heated, was discovered in 1821 by Seebeck. Since that time the importance of thermocouples for measuring temperatures has grown tremendously. Although the cost of the electrical unit which consists of a thermocouple and potentiometer is about double that of gas and liquid filled systems, it has many important advantages.

If more than one temperature is to be recorded, say as many as ten, the cost of the electrical system would be much less than gas or liquid filled systems because all 10 temperatures could be recorded on one chart whereas it would take five charts with either the gas or liquid filled systems. Potentiometer installations also have the advantage of being able to measure temperatures beyond the range of liquid and gas filled systems; measuring temperatures at greater distances from the recorder; and giving faster response.

Common thermocouples are iron-constantan which has a maximum temperature limit of 1500°F, and copper-constantan which is used below 400°F. Combinations of other metals are used in various other temperature ranges.

Thermoelectric systems are extensively used in high temperature measurements such as furnaces, dryers, lehrs, ovens, and autoclaves. They are also used extensively in the oil industry especially in catalytic cracking operations. A typical fluid catalytic cracker requires 19 temperature controllers[1] and 33,000 feet of thermocouple lead wire.

Pressure or Vacuum

With the possible exception of temperature, pressure or vacuum is often the most important variable to measure and control in industrial processing. A variety of elements designed especially for the range and operating conditions is required to meet the pressures and vacuums encountered in modern plants. The most widely used industrial types of pressure elements are:

1. Bourdon tube
2. Spiral or helix
3. Spring and bellows
4. Bell type

Bourdon Tube

The simplest and most common type of pressure

(1) McDonald, M. "Automatic control of a fluid catalytic cracking unit" Instrumentation Jan.-Feb. 1947

measuring element is the Bourdon tube. Figure 2 represents the mechanism of a typical Bourdon tube. Not only is this tube used extensively in small, dial type indicating gauges and controlling industrial instruments for pressures ranging from 15 to 10,000 psi; but also its operating principle is used in the spiral and helix.

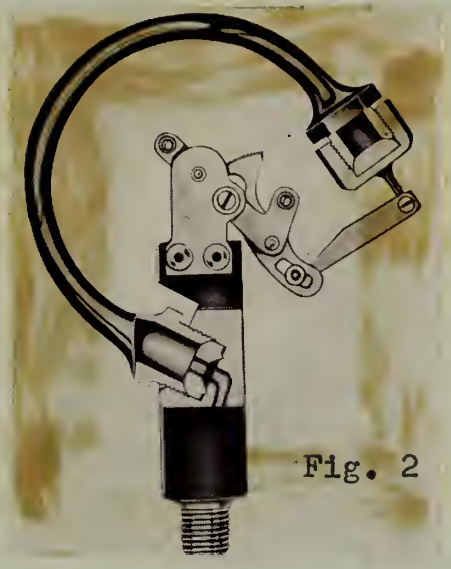

Fig. 2

The actuating element comprises a thin walled tube which has been flattened on diametrically opposite sides to produce approximately an elliptical cross section. The tube is then bent into an arc of a circle as illustrated. When pressure is applied at the open end of the tube, the tendency is not only for the original round cross section of the tube to be restored, but also for the tube to straighten. Actually, to a small degree both of these changes take place, and thereby move the free end of the tube a sufficient amount to position a pointer across a graduated scale. A sector and pinion design is used to amplify the tube movement.

Pressure elements based on the Bourdon Principle do not require a spring to balance the force due to a pressure increase or decrease, since the elastic modulus

of the metal is used to graduate the deflection. Although the exact effect of pressure in causing a movement of the tube involves quite complicated mathematics, it has been shown that, within prescribed limits, a straight line calibration can be obtained for the free end movement of the tube, permitting equal graduations on the dial.

Basically, the tube must be designed so as to obtain the maximum movement per unit change in pressure together with the minimum of hysteresis and without permanent deformation.

Materials generally used for Bourdon tubes are phosphor bronze, beryllium copper, stainless steel, and chromium alloy steels. The most common material for lower pressure ranges is bronze.

Bourdon Tubes are used in practically all pressure gages on steam lines, pressure retorts, polymerization kettles and autoclaves.

Spiral and Helix

Both the spiral and helix pressure elements are actually Bourdon tubes wound as a flat spiral or a helic consisting of several turns. In these elements, the restricted end movement of the open Bourdon tube is overcome. The spriral or helix arrangement in no way affects the theory of the Bourdon tube; it merely gives a summation of the end movements of a number of such tubes, resulting in greater movement of the free end. In industrial recording

type gauges, this effect is decidedly advantageous for movement of the pen over a relatively wide arc, and has led to the almost universal use of the spiral and the helix for pressures in the range of about 10 to 4000 psi.

These instruments are used in the recording of pressures on steam lines, pressure retorts and auto claves.

Whereas, in the Bourdon Tube gauge, it is necessary to amplify the end movement through a pinion and sector design in order to obtain sufficient pen travel, the spiral or helix has ample end movement and can be directly connected to the pen or pointer shaft assembly by a simple link. All necessary amplification of this movement is accomplished solely by the lengh of the pen or pinter arm.

This direct linkage reduces friction to a minimum eliminates inertia and lost motion, increases accuracy and response, and prevents undue mechanical failure which can occur in the pinion and sector design. The accuracy of the spiral type instrument, can be held within 1% of full scale- an accuracy usually ample for industrial pressure measurement and control.

Spring and Bellows Gauges

There are pressure ranges which cannot be

measured satisfactorily with the gauges previously described. Spring opposed bellows have been developed for intermediate and low pressure ranges. The intermediate range type consists of a metallic bellows, the latter being connected to a pressure source. Figure 3 , page 29 is a spring and bellows arrangement. Pressure, acting on the outside of the bellows tends to compress the bellows, moving its lower free end upwards against the opposing force of the spring. A rod resting on the bottom of the bellows transmits the vertical motion through a suitable linkage into pen or pointer movement on a linear basis.

The intermediate range unit is used to measure pressures with full scale values between 100 inches of water and 15 psi gauge or vacuums with full scale values between 10 and 30 inches of mercury. For lower pressures and vacuums, a larger bellows with the pressure connected internally is used. This creates an appreciably greater force per unit pressure change which acts against the opposing spring force.

Figure 3

Bell Type Pressure Gauge

Pressures in the range of one inch of water cannot be detected with sufficient accuracy by either the Bourdon method or by the spring and bellows arrangements. Furnace and kiln pressures lie in this range and must be held within narrow limits in this range for most efficient operation.

The actuating element of this type comprises essentially two bells which are suspended from the ends of an even arm balance beam and immersed in a tank containing oil of the required viscosity. The measured pressure line terminates beneath the right-hand bell with its opening extended above the oil level.

The change in measured pressure beneath the right hand bell will affect the scale pointer proportionately providing the deflection of the balance beam from its position does not exceed five degrees. The sensitivity is directly dependant upon the sensitivity of the balance beam.

The bell type gauge is a highly accurate type of pressure measuring device. Ranges from -0.05 inch of water vacuum to 2 inches of water pressure, with a sensitivity of 0.0005 inch of water can be measured. From this it can readily be seen that the control can be held within very small margins on minute pressure changes.

The gauge is very delicate and must be protected from appreciable shocks and sudden pressure surges.

Fluid Flow

Fluid flow meters stand high on the list of essential industrial instruments. Since fluids are an important element in manufacturing processes, modern industrial economy demands accurate knowledge of their behavior. To measure and record the total flow and rate of flow of any fluid under varying conditions of temperature and pressure is of vital significance as a check on the efficiency of equipment and as a definite factor in cost finding.

Rhodes (1) classifies flow meters in two classes--namely inferrential and volumetric types. In general differential and area type meters falling under the inferrential classification are the only ones used in the control of process flows in pipes. Control is generally accomplished by a differential flowmeter in which the rate of flow is determined from a measurement of the differential pressure created across a restriction in the line of flow.

The theory behind these flow measurements is derived from the law of conservation of matter and Bernoulli's theorm. From this, flow may be measured by

(1) Rhodes- Industrial Instruments for Measurement and Control McGraw-Hill Book Co. New York 1941 p 187

two methods---(1) by measuring the differential pressure across a restriction of constant area; (2) by measuring the area or velocity with a condifferential pressure across a restriction to flow.

The differential flowmeter operates on the principle that there is a different differential pressure created across a restriction in the flow line for each rate of flow. The restriction may be an orifice plate, flow nozzle, or venturi tube.

The orifice plate is the most common form of restriction and consists of a metal plate with a circular hole of known diameter cut in the center. The plate is inserted in a pipe carrying a liquid. Pressure taps are located on either side of the plate and the difference between upstream and down stream pressure measured by a manometer which is an instrument that translates the pressure differential into a height of this column of liquid.

The manometer operates from a metal float in an enlarged leg of a mercury U-tube. The metal float follows the changes in level of the mercury in the chamber as the differential pressure changes with the rate of flow. The motion of the float is transmitted through a pressure tight shaft and is utilized for operating the recording pen.

The second type of flow meter utilized in industrial control is the area meter that operates on the principle that there is a different orifice area for each rate of flow and consequently the differential pressure is constant for any rate of flow. This is carried out by means of a float supported in the stream of fluid by the differential pressure across the float. As the flow increases, the float moves upward, thereby increasing the area of the opening until the differential pressure at the float just balances the weight of the float. Generally this movement is translated by electrical means to the controller.

Liquid Level

Liquid level measurements represents the forth variable to be covered. The reasons for making liquid level measurements are: (1) to obtain exact information on the amounts of raw materials in storage (2) to check the quantities of reactants to be added to a batch process, and (3) to control the liquid level in a reaction apparatus that is part of a continuous process. The latter use has become very important in the continuous process operation that has increased chemical production so greatly.

Liquid level instruments may be classified in

the following groups:

(1) Visual indicators
(2) Float actuated instruments
(3) Electrical contact types
(4) Static pressure types
(5) Pressure differential types

Visual Indicators are the simplest and most widely used methods of measuring liquid level. Sight glasses consisting of a glass tube mounted on the side of the tank and connected to it by means of pipes at the top and bottom. The liquid rises in the tube to the same level as that in the tank and by putting a scale calibrated in gallons, pounds, or percentage of full capacity, the amount of liquid in the tank can be determined.

Float actuated instruments and electrical contact types are also used to indicate liquid level but the static pressure type and pressure differential instruments are the types most used in recording and controlling instruments. The theory behind the static pressure type of instruments has been explained in the section dealing with pressure variables. Since the static pressure at the bottom of a vessel varies directly as the head of liquid above, all that is necessary to obtain an indication of the liquid level in the tank is to measure the pressure existing at the base and to calibrate the measuring instrument in terms of feet, inches, gallons, or pounds. A recording instrument utilizes a bellows,

spiral, or bell and diaphram type of actuating element combined with a linkage to multiply the movement of the actuating mechanism and draw a line on the recording chart.

The pressure differential type of liquid level recorder as described in the section on fluid flow with the differential pressure created by the height of liquid in a tank rather than a constriction in a pipe. Fig. 4 shows a recording manometer (flow meter) installed as a liquid level instrument.

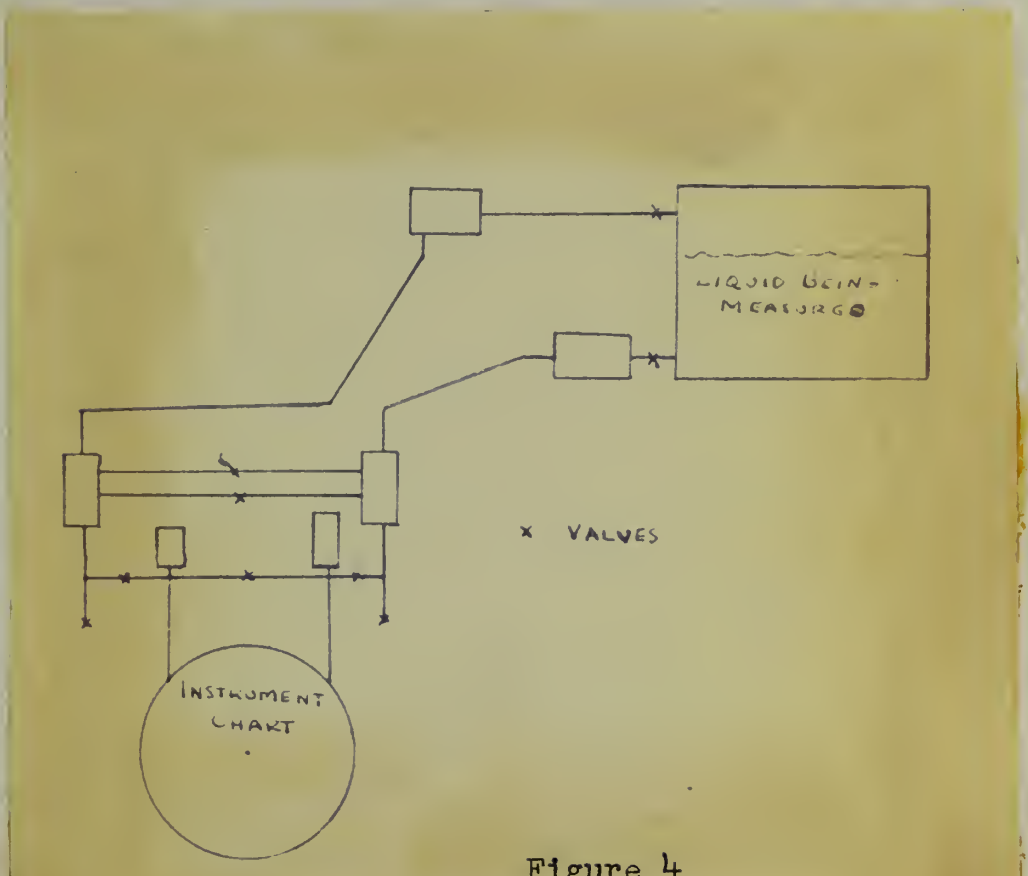

Figure 4

CHAPTER III AUTOMATIC CONTROL AND CONTINUOUS PROCESSING

The most significant among wartime advances in the engineering of chemical processes has been the marked increase in the trend toward automatic operation and control. The enormous quantities of aviation gasoline and synthetic rubber required for World War II were produced mainly in continuous units of tremendous throughput and were entirely dependent upon modern process control instruments for their satisfactory operation.

This trend toward continuous operation and automatic control is even more significant today with the present status of business. Some advantages of automatic control in chemical processing are:

1. Improved product quality and uniformity
2. Increased production
3. Cost reduction resulting from:
    a. Fuel savings
    b. Lower labor costs
    c. Reduction of spoilage
    d. Reduction of space required for process equipment

Any of these advantages may be sufficient to justify the installation of automatic control. Although automatic control is far more essential to continous operation it is used almost as extensively in batch processes. The polymerization of vinyl chloride, a batch operation, is equipt with proportional automatic controllers in order to eliminate manual adjustment. The continous process usually contains all of the control problems present in batch processes and since continous operation relies to a greater extent upon

automatic control, this section will deal with automatic instruments as applied to a continuous process.

What is automatic control?(1)

Automatic control can be defined as the maintenance of a balanced state in a process by measuring one of the conditions representing the balance and providing an automatic counteraction to any change in the condition. The balance in the process may be a balance of any form of energy, very often heat or pressure.

A controlled system is so called because it consists of a process and control system. The process is the operation or function in which a balance of conditions is being maintained. Figure 5 illustrates the various components of a controlled system.

For example, measurement of temperature is accomplished by a thermometer bulb which is called a primary measuring element. Since the temperature of the outflowing water from the process is measured, the controlled medium is the water in which a variable (temperature) is controlled. The primary measuring means of the controller is the thermometer.

The controlling means consists of the controlling

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(1) D.P. Eckman, 'Principles of Industrial Process Control' John Wiley and Sons, 1945 pp 4-5

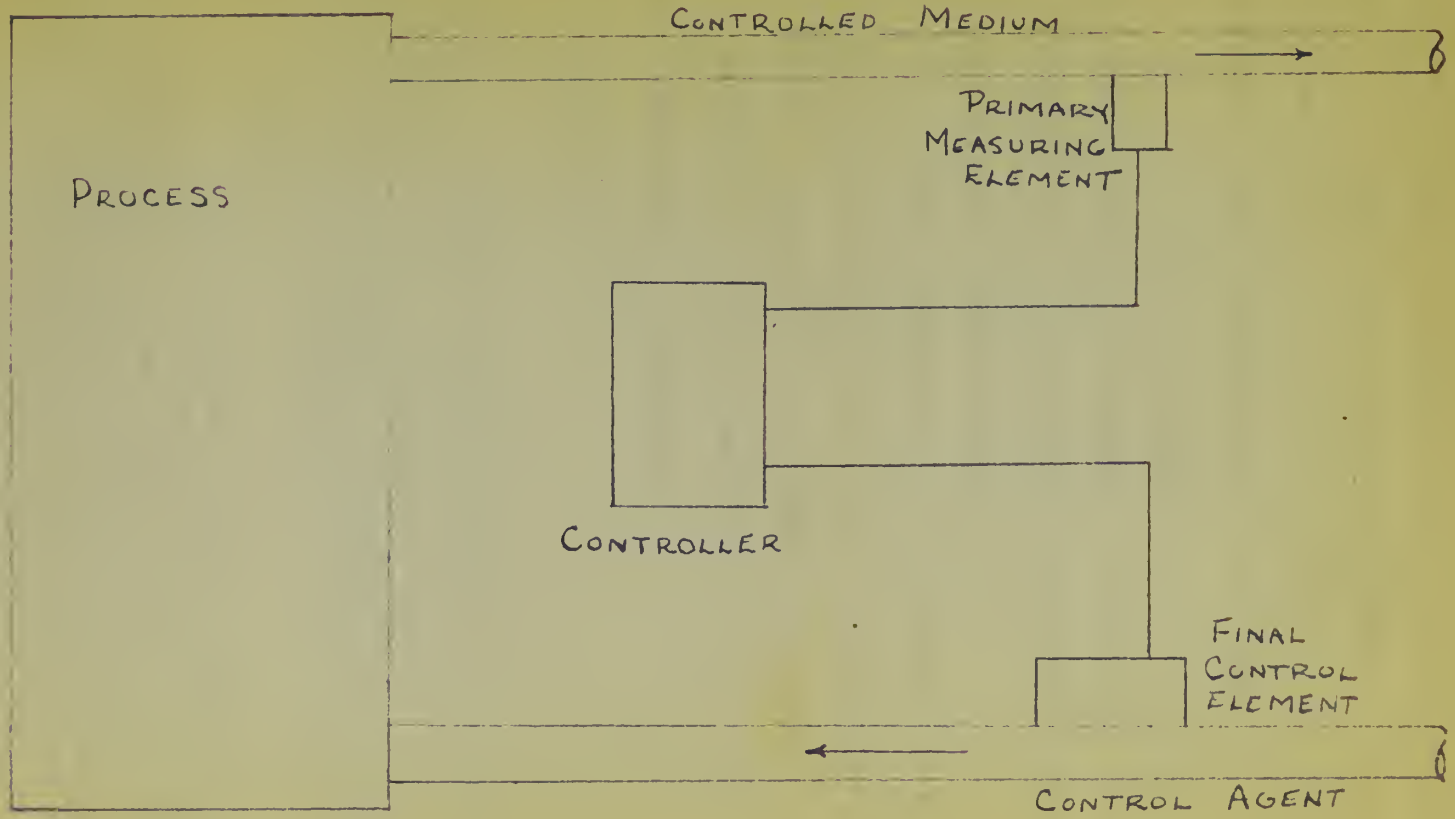

Figure 5 Elements of a controlled system

mechanism and the controller, such as an electric contact, and a final control element which may be a control valve for adjusting the flow of fuel gas to the burner. The fuel gas is a medium for affecting changes in heat flow to the bath and is called a control agent. The control agent is always adjusted by means of the final control element.

A control system is made up of the measuring means and the controlling means. It generally consists of the controller and all auxiliary mechanisms used for the purpose of controlling the temperature.

The process is the operation of heating water to a controlled temperature. The process equipment is the physical apparatus, aside from the control system, used in carrying out the process operation. The process is the operation or function.

Control (1)

Automatic control is accomplished by a circle of events. Beginning with a change in the control variable and ending ultimately with a forced return of the variable to the desired level. Meanwhile, however, the controlled variable has departed for a period of time from the desired value. Such a change in the state of balance in the process is inevitable because it is the basis for action by the controller.

Let us suppose that the temperature of a water bath is being controlled manually by setting a hand valve to regulate the flame under the bath. If the operator were watching a thermometer placed in the bath he would open the valve when the temperature goes below the desired point and close the valve when the temperature rises above the desired

(1) D.P. Eckman, 'Principles of Industrial Process Control' John Wiley and Sons, 1945 pp 4-5

point. But in order to know when to readjust the valve the operator must observe a change indicated by the thermometer. No matter how closely the operator can read the thermometer, the change in temperature has already occured before an adjustment of the valve can be made.

The action of automatic control is dynamic because of the continuous, changing character of the actions within the controlled system. Automatic control is rarely a steady state of balance but operates to maintain process conditions within desired limits.

It is the purpose of the controller to hold to a minimum any deviation from the desired balance of the process.

Automatic process control is a complex study of time lags in a process. These lags may be inherent in a process such as the time required to heat up a large amount of fluid once the energy is increased, time lag in the controller usually due to friction of the parts, measuring lag due to temperature difference existing at any time between the true temperature of the product being measured and the temperature indicated by the measuring instrument. Figure 6 is a diagramatic representation of the lags in a controlled system.

Good design will hold these lags to certain desireable proportions but cannot eliminate them. Once the process is designed, the problem remains of choosing a controller mechanism with characteristics that will assure the minimum deviation from the control point. Good control design is measured by the simplicity of the control mechanism. This simplicity represents lower first costs for equipment and lower maintenance costs. Too often elaborate controls are

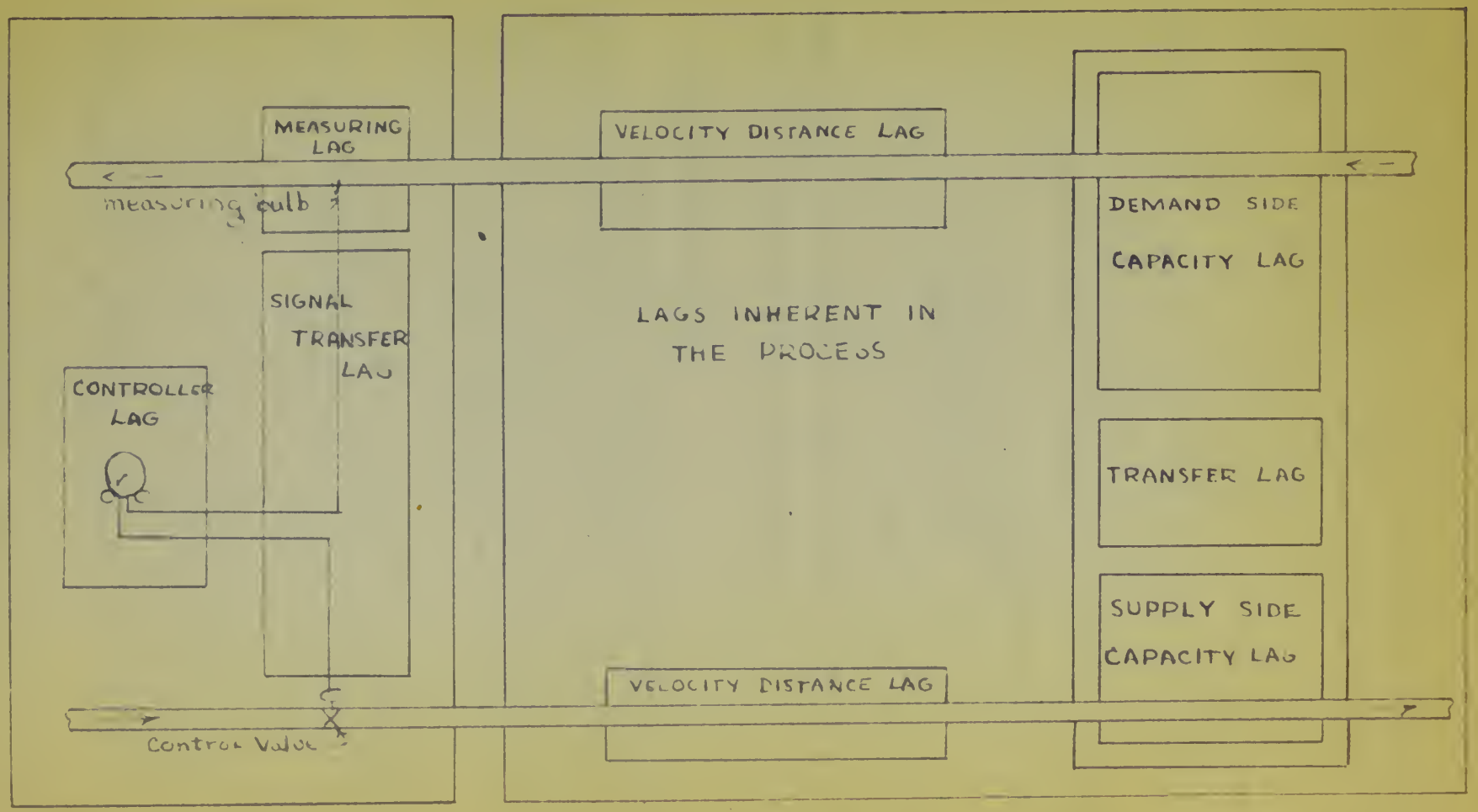

Figure 6 Lags in a controlled system

installed on the process where the demands of the system never require the use of the more complex response for which the controller was built.

Assuming that a process has been designed properly, there are four modes of control that can be chosen to keep the process operating at a set point.

These modes of control may be listed as follows:

1. On-off or two position control
2. Proportional control
3. Proportional reset
4. Derivative action

The four modes of control listed above describe the action of the final control element, such as a motor valve for controlling steam or fluid flow.

On-Off Control (1)

This is the simplest and most often used type of control mechanism and is clearly described by its title. Control of this type is also known as two position control, from the fact that the valve can assume only two positions regardless of the temperature of the process. The two positions usually assumed are the open and shut positions of the valve. Although valves are made that may be adjusted for other than these positions.

The valve may be electrically operated, compressed air operated, hydrolically operated, or operated by the temperature-measuring fluid. In all cases, however, the characteristics of the valve that it moves rapidly and positively from one position to another depending on whether the temperature of the process is higher or lower than a certain prescribed point. When the valve is open the heating rate is too high; when it is closed the rate of heating is too low. In order to prevent the large disturbance that may result from having the supply cut off completely by the control valve, a bypass valve is often arranged to admit a steady supply of a minimum amount of heat known to be needed

(1) T. J. Rhodes, 'Industrial Instruments for measurement and Control' McGraw Hill Book Co. 1941, pp 405-407

and to have the on-off valve supply the additional variable amount for control. This method may produce difficulties and can be used when the system has a number of unfavorable characteristics or where rapid variations in rate of load changes are encountered. They are ideally suited where the only load is that of maintaining temperature against radiation losses. In such cases storage capacity is relatively large, load changes are small and valve adjustments are easy to make.

Proportional Control

The first refinement of the simple basic on-off control was the construction of a control mechanism that would cause the control valve to assume a position proportional to The deviation of the temperature from the point of control. This type of controller there is one position of the controlling valve for each temperature within the temperature range encompassed by the open and shut position of the valve. This temperature range is known as the 'Control band'

This type of response may be defined as the valve movement per unit of controller pen movement.

Proportional reset

A further refinement of mode of control was the development of the proportional reset controller. This type of control action gives a rate of valve movement per unit movement of the controller pen. It should be used where the process load changes are slow, where the transfer lags are small or moderate but where the process reaction rate may vary any amount.

Derivative action

The most elaborate type of controller mechanism is the derivative action controller. This type of valve

action is valve movement for the rate of movement on the controller pen. Here the magnitude of the upset is dependent only upon how fast the measuring pen moves. This type of controller can be used where process reaction rates, transfer lags, and process load changes vary to any degree.

Automatic control and continuous process

Automatic control as briefly described, is essential to continuous operation. Some processes are not yet adaptable to continuous operation because of a lack of suitable control methods.

The trend toward continuous operation is increasing due to savings in plant investment, lower labor costs, increased production and lower operating costs. In batch-wise processes the batches must be started on a predetermined scheduled and throughout the run conditions are constantly changing. When a new operator comes on duty, at shift change, it is necessary for him to review the log of each piece of equipment under his control in order to know the exact condition of each batch. Potential down time may occur when a new batch has to be started at or near the close of one shift and is consequently left to the man coming in on the later shift.

With a properly designed continuous process, process conditions at any point are substantially constant from time to time, day to day, and even month to month, thus eliminating the above potential down-time.

In batch-wise operation the number of operators required is generally greater. This is due, in part, to the necessity of handling material in process and, in part, to the marked tendency of unions to limit the number of operations under control of one man. In the continuous type of processing there is no such handling and actual control is had with instruments which are located at a central control point and the operator's duty becomes mostly that of making sure that the instruments are functioning in the proper manner, making scheduled valve changes, and the like, where automatic timing devices are not provided.

The features of a batch-wise operation can be minimized by complete instrumentation included time cycle control. In any case before a batch process is made continuous, the economics of instrumentation should be considered. It should be noted that frequently the additional cost for complete instrumentation may overbalance the saving on overall equipment cost made possible by batch-wise processing over continuous processing, where either method is possible. (1)

Plant Investment

In 1933 the chemical industry in this country had an average investment in physical assets approximating $7,000 per employee. In 1942 this ratio had risen to about $10,000 per employee, unit costs had decreased as did selling prices-better economy in other words. Specifically, as regards

(1) R. M. Crawford, 'Economic comparison of batch and continuous processing', Chemical Engineering, May 194[illegible] pp 109

known data relating to the commercially successful continuous processes, this ratio in 1942 appears to be about $30,000 per employee - three times the general average.

From this it appears that the labor costs for continuous processes have been reduced in much greater proportion then, that continuous processes, in general, can bear a high plant cost on the basis of greatly reduced labor costs.

Continuous processes cannot displace all, or even most, of the existing batch-wise processes within the forseeable future, but there should be an increase in their development and application to individual merit as they can be made to fit into the economic structure of the industry.

In conclusion the following list of factors shows some of the problems that should be met or considered in determining whether a process should be continuous, batch, or some combination of the two. In all cases the use of automatic process control instruments is vital to success.

Factors: (1)

Volume of market	Sensitivity of process
Stability of market	Ease of control
Product acceptance	Cost and availability of suitable automatic controls
Seasonal nature of market	
Financial strength of company	
Size of the plant	Rate and order of reaction
Cost of research and develop	Safety
Wage level	Cost of equipment
Union attitude	Prospects for obsolescence
Attitude toward overtime and Sunday work	Aging or holding time requirements
Unit value of the product	Storage requirements
Processes involved	Frequency and ease of cleaning
Comparative quality by batch or continuous method	Physical limitations of plant size
Uniformity of raw material	Maintenance and replacement

Many of these factors were taken into account in the design of a continuous method of purifying carbon disulphide. (See Chapter IV)

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(1) Continuous Processing- Chem & Met Reports
Chemical Engineering, May 1945 p 106

CHAPTER IV CASE HISTORIES

1. Synthetic methanol

Thirty years ago there was no production of synthetic methanol. In 1923 I.G. Farben delivered the first synthetic methanol in New York City duty paid at 40 cents a gallon or less than half the going price for domestic wood alcohol.

In 1927 a DuPont subsidiary began the first synthesis of methanol in this country. It was essentially an experimental unit in conjunction with an existing ammonia synthesis plant. The capacity of this plant was about 500,000 gallons of methanol per year. Several months later the Commercial Solvents Corporation started synthetic methanol production in Peoria, Illinois. The capacity of this plant was announced to be 1,300,000 gallons per year.

Methanol is used extensively in the manufacture of formaldehyde, a raw material in the plastic industry, and in the manufacture of antifreeze. In 1947 over 80% of methanol production went into the manufacture of these two products.

Post World War II expansion of production has been phenominal even for this traditionally fast growing industry. From 1927 when production was 1 million gallons, the total production has risen to over 80 million gallons in 1947 and is expected to be double that in 1948. The first six months of 1948 showed production to be about 70 million gallons.

The demand is expected to be in the vicinity of 200 million gallons per year in the not too distant future with the expanding demand for formaldehyde and the expanding market for anti freeze.(1)

Synthetic methanol can be made from several raw materials and methods of production. At the Commercial Solvents Sterlington, Louisiana plant, natural gas is used as the raw material and the method of manufacture is through the catalytic hydrogenation of carbon monoxide.

Automatic instruments are featured at this plant and some very noticeable advantages have been realized. Extensive instrumentation with accompanying automatic controls has made it possible to produce 45,000 gallons of methanol per day at Sterlington with about half the labor force necessary at the 10,000 gallons per day plant at Peoria, Illinois.(1)

Automatic instruments are featured at this plant and the control system is particularly ingenious. Most gas flow meters in the plant operate by measuring the pressure drop through a fixed orrifice. Assuming the density and other physical factors of the flowing fluids remain constant, the rate of flow through such an orifice varies with the square root of the differential pressure across the orifice. Automatic control valves are of the air

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(1) Synthetic Methanol Production - Report Industrial & Engineering Chemistry Dec. 1948

(2) Ibed. p 1597

actuated diaphragm type. Temperature measurement is entirely by thermocouple. Temperatures are measured at 68 points in the catalyst basket and at 8 points on the exterior of the converter shells.

Pressures are measured throughout the high pressure system by Bourdon tubes. All compressors are equipt with automatic cutouts as well as emergency switches located at strategic points in the compressor house.

Automatic liquid level controllers are mechanical flow type throughout the plant. All methanol hold tanks are equipt with both float and bubbler type meters.

Instrument indicators are centralized at two control boards. The entire gas reforming operation and the distillation products of the converters can be monitored and controlled from a station in the control house. A second control station in which the converter operation can be followed and adjusted is located in the compressor house. It is not necessary to have an operator continually present at these stations because under normal conditions the process proceeds automatically.

2. Sulfuric Acid Production

Sulfuric acid is the most important product of the inorganic chemical industry. It enters into so many different processes in large amounts that the sulfuric acid market may be considered a better barometer of business

conditions than even the iron and steel market. This is not only because sulfuric acid has fully as many applications as iron and steel, but also because, since it is rarely stored, its production and consumption respond more quickly to changes in business activity. Sulfuric acid not only represents the condition of manufacturing industries, but because of its use in the manufacture of fertilizer, it is equally significant as a borometer of agricultural conditions. It has even been said that the industrial activity of any country can be measured by its consumption of sulfuric acid.

Sulfuric acid is manufactured by both the chamber and contact process. The chamber process has been operated for 70 years with practically no significant changes in equipment and methods. Due to the fact that the chamber process can produce only dilute acids, it will eventually be replaced by the contact process.

Table III shows the uses of sulfuric acid as a percent of the 1940 production.

TABLE III USES OF SULFURIC ACID (1)

Use	Percent
Fertilizer	24.7
Petroleum refining	13.9
Iron and steel	13.2
Chemicals	11.9
Coal products	9.8
Metalurgical	7.0
Paints and pigments	6.2
Rayon and cellulose	5.1
Explosives	1.9
Textiles	1.4
Miscellaneous	4.9

(1) Inorganic Chemical Technology, Badger & Baker McGraw Hill Book Co. 1941 p 38

Sulfuric acid is ordinarily sold as 62%, 78%, or 93% acid. Acids stronger than this are usually referred to as the percent of disolved SO_3 in 100 % acid and are called oleum.

In 1945 the production of sulfuric acid reached 9 million tons annually or almost double the production in 1939. Of this increased production, 1½ million tons was due to expansion for war uses. In 1947 additional capacity of 1.7 million tons was constructed. This increase in acid production does not reflect all the the new capacity installed for a number of outmoded units have been dismantled and replaced with modern units.

Almost all the new facilities built since the war employ the contact process with vanadium catalyst. The modern contact plant is theoretically the same as that of ten years ago. The design has been improved, however, so that it bears little physical resemblance to prewar units. the opportunity for intensive study of the process has resulted in simplification of design, greater ease of operation, lower maintenance requirements, higher yields, and higher degree of continuity.

One of the major innovations in plant design has been the introduction of outdoor type of construction, where only control room, blower, and feedwater pumps are enclosed. Many producers of sulfuric acid have found that the increased efficiency and economy of postwar units justify their installation as replacements for old units.

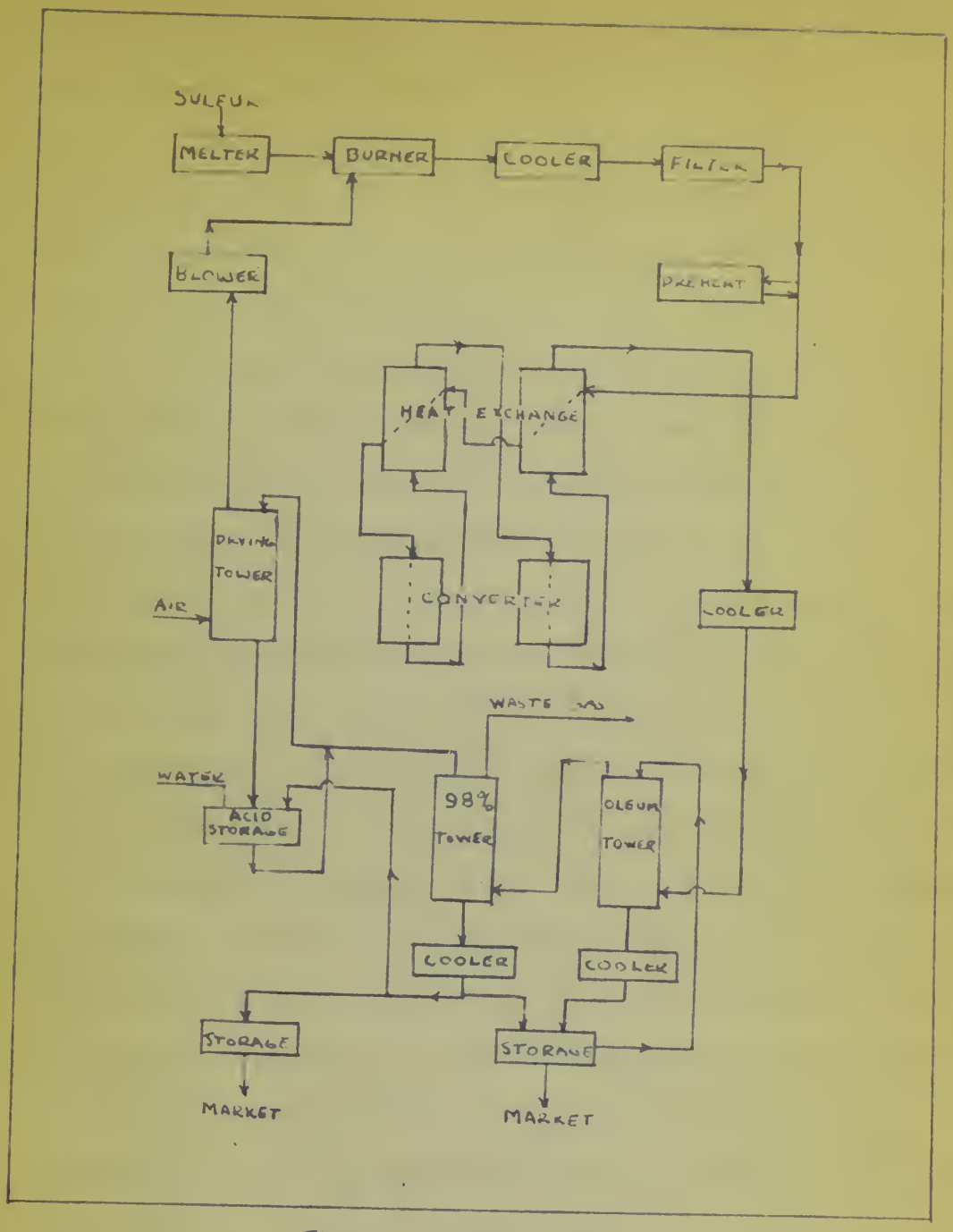
Monsanto Chemical Co. found it economical to dismantle four small 20 year old units after the war and replace them with one large unit of new design.

The acid plant at Monsanto, Illinois consists of three completely independant sulfur burning units. The third and latest constructed has a rated capacity of 200 short tons of 100% sulfuric acid daily. The flow sheet on the following page represents the manufacture of contact sulfuric acid at the Monsanto, Illinois plant.

Instrumentation is an important feature of this unit, as it allows the entire operation to be handled by one operator per shift. The centralized control room contains all instruments necessary for the operator to check performance throughout the plant.

Control of temperature is vitally important, if the plant is to operate under optimum conditions. This includes temperatures of the gases passing through the filter, through the heat exchanger, through the catalyst mass in the converter, through the sulfur trioxide cooler and through the absorption towers.

The temperature of the gasses in contact with the catalyst is most critical because of the reversible nature of the reaction by which sulfur dioxide is oxidized to sulfur trioxide. The overall efficiency of the plant is determined by this temperature and therefore it is constantly recorded and observed. Unless all conditions affecting the production of acid by the contact process are known and held within narrow limits, it is impossible



FLOW SHEET OF

CONTACT PROCESS FOR SULFURIC ACID

Figure 7

to keep the process functioning at maximum throughput with the highest rate of conversion.

Automatic controls eliminate the need for even one operator in many emergencies. One such device stops the sulfur pump and air blower in the event of low water level in the steam drum.

The advantages of instrumentation especially temperature controllers, include a constant check on conversion efficiency and an accurate record unaffected by ommision or typographical errors on the part of operators. The record is not only valuable for indicating trends which signify changing conditions of operation, but in the event of otherwise unexplained process difficulties they can be used to locate causes. Thus the record can be used as a forecast for future trouble and as a warning of the need of preventative action. In addition, however, it permits analysis of conditions which have resulted in upsets after they have occurred and enables the operator to avoid recurrences of these unnecessary interruptions. A complete temperature record is actually a source of extremely valuable process research data at a relatively low cost.

3. Testimonials (1)

Savings estimated at $13,000 per year were

(1) Van Brent, "18 proofs that instruments save money" Factory Management November 1933 pp 449-450

reported in a Southern paper mill. Recording thermometer and pressure gages have led to improvement in quality of product and reduction in fuel consumption.

Savings of more than $650 per year in cost of steam was realized by an Eastern chemical plant through installation of an automatic temperature control for one unit of production.

Manufacturer of non-ferrous alloys installed a meter which records steam flow, draft and flue gas and steam temperature. Changes in practices indicated by study of these records have resulted in savings of $260 per month. The meter pays for itself every few months.

A stove manufacturer saved $2600 in fuel oil by installing a recording pyrometer and automatic control of oil feed lines. Increased production was also realized due to uniform temperature.

Recorder for steam and air flow and flue gas temperature of Southern paper mill saved $24,000 by increasing average evaporation per pound of coal from 8.9 to 9.6. This equipment pays for itself every 46 days.

A manufacturer of enameled wire reported that rejections due to improper annealing or baking of the coating were cut from 7% to 2% by installing automatic temperature controllers. Savings of $3,300 per year were reported or a return of 76% on the investment.

An oilcloth manufacturer improved quality and uniformity of product by installation of temperature controllers in drying ovens. The savings were estimated at $1500 per year.

A mid west soap factory was contemplating additional boiler capacity to meet increased demand for steam. Steam flow meters installed meanwhile gave information which resulted in increased steam output through changes in firing methods. The new boiler capacity was therefore unnecessary and savings in cost ran into several thousands of dollars.

4. Pharmaceuticals:

The use of process control instruments has become vital to the processing and synthesizing of modern pharmaceuticals.

Over the years, the trend towards using synthetic chemicals as ingredients in pharmaceuticals has increased to

the point where, today, chemical synthesis constitutes a very important part of pharmaceutical production.

This is particularly true of the G. D. Searle Company of Chicago, Illinois. In many cases they find it more economical to synthesize than to refine chemicals found in nature. In addition many compounds cannot be f found in nature and must, therefore, be manufactured. (1)

Control instruments are used extensively in maintaining desireable yields of manufactured chemicals as well as safeguarding their purity. In addition, control charts are used as a basis for determining costs of various items, such as steam, that are used in the process.

Many chemical reactions are performed in the synthesis of organic compounds including such technical ones as methylation, chlorination and Friedal-Crafts which produce items such as drugs, anesthetics, and antiseptics respectively.

These organic chemicals are quite sensitive to temperature, many of them decomposing at fairly low temperatures. The speed of most chemical reactions approximately doubles for every 10 degree rise (Centigrade) in temperature. Obviously, where reactions are carried out in closed vessels, strict attention must be paid both to temperature and pressure, not only from the standpoint of product yield and quality but also as a consideration of safety. Should the temperature

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(1) Instrumentation March 1949 Brown Instrument Co.
Taylor Technology Spring Issue Taylor Instrument Co.

become too high, undesireable side reactions or decomposition may occur, or pressure may be built up in the kettle; whereas at temperatures too low, thereaction will not proceed to completion.

Control instruments, especially temperature and pressure controllers, are used extensively to control these reactions and to constantly guide operators.

Another important phase of pharmaceutical manufacture is the processing of large quantities of materials to produce relatively small quantities of valuable antibiotics.

In the manufacture of streptomycin, as in the case of other fermentation processes for the production of anti biotics, the process requires an enormous amount of raw materials compared to the yield. On a monthly basis, some 10,000,000 pounds of materials, including solvents which are recovered, and 45,000,000 gallons of process water, are required to produce 250 pounds of finished streptomycin.

The manufacture of streptomycin consists of four main processes: fermentation, recovery purification and finishing. The fermentation phase includes inoculation and submerged fermentation with the agent "streptomyces griseus". The final fermented broth contains 0.005 percent streptomycin.

To obtain this relatively small amount of streptomycin present in the fermenters, it is important that extremely close control be exercised over all the processing operations. These include not only the constant and uniform

control of air flow, temperature and pressure, but also the constant guard against contamination by maintaining super sterile conditions. These functions are all automatically maintained by means of instruments.

Instruments are also vitally important to the recovery operations since they are continous rather then batch operations like the fermentors. These continuous operations include filtration, extraction, concentration by evaporation and precipitation and drying.

The measurement and control of process variables is extremely important for the efficient operation of this process. This represents an investment of well over $200,000 in instruments. However, in a process so definitely dependent on adequate instrumentation, this figure represents a comparitively small part of the total cost.

It is very evident that industrial instrumentation makes it possible to successfully operate this process. These instruments take the responsibility for maintaining a high quality product and guarding against any contamination. They relieve the operator of many control function responsibilities, thus allowing more time for other important duties. Such a large investment in raw materials demands efficient operation to produce every possible ounce of this precious drug.

Cost of Operating Labor versus instruments (1)

The following discussion represents typical cost of instrumentation. The figures are average costs for operating labor; instrument capital costs; and instrument repair, maintenance, and operating costs.

Cost of operating labor:

Operator pay is assumed at $1.91 per hour (close to average pay rate for chemical operator or oil refining helper in the Texas Gulf Coast area); cost of vacation, holidays absenteeism, 6.66%; cost of social security,workmans' compensation, pension, 7.3%. Therefore for a continuous process with one man per shift, the labor cost will be 1.91 x24 x365 x1.1396 = $19, 067 per year.

In addition to direct labor charges, there are various over head charges that are functions of the direct labor. These include such items as safety, sanitation, locker room facilities, and general supervision.

A rough estimating rule for process evaluation is to calculate plant overhead at approximately equal to 50% of the direct labor plus 2% of the capitol. This would add $10,000 to labor, thus making thecost of a man per shift per year about $29,000.

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(1) How Good Instrumentation can Save dollars. C.S. Comstock Chemical Industries, Dec. 1948

Cost of instruments

The following two illustrations represent typical capital expenditures for instruments.

1. Flow recorder controller operated by transmitter

Transmitter	$275
Receiver	360
Installation labor	210
Installation material	330
Control valve	190
Total	$1365

2. Differential type recording liquid level controller

Instrument	$360
Control valve	190
Installation labor	100
Installation material	169
Total	$819

The prices will vary widely with local conditions, with the size of the control valve, and with the actual instrument selected. However, it is safe to say that it will cost at least $1,100 for the average installed instrument.

Cost of instrument repairs, maintenance and operation

Experience has shown that the total cost of operating a control instrument is about $70 per year. This includes repairs and maintenance, chart changing, statistical analysis, air, and utilities.

Repairs and maintenance items include preventative maintenance, emergency repairs, and necessary calibrations, as well as supervision directly charged to the instrument department.

Therefore the total yearly cost of a control instrument is:

Depreciation @ 10%	$110

Investment return 20%	$220
Operation charges	$ 70
	$400

The foregoing figures present an interesting comparison between manual and instrument operation. The use of instruments to lower labor costs has been demonstrated many times. One of these examples is in the production of synthetic methanol where 45,000 gallons of methanol are produced with half the labor force required to produce 10,000 gallons at an older plant.

The desireable minimum number of men in any one operation area is two because of safety precautions. The promise that instruments will save labor is based on three considerations: first, the instrument is rugged and reliable and will function properly as designed; second, the instrument was properly selected and installed to measure and control a significant variable; and third, the instrument is maintained in good condition and is properly calibrated and adjusted.

The first requirement of reliable well built instruments is in the hands of the instrument manufacturers. Exceptionally keen competition and the development of modern mechanical and electrical science have resulted in a wide choice of instruments from which the instrument engineer or process design engineer may wish to select.

The second and third requirements of proper selection and maintenance are primarily in the hands of the process designers and the plant operating management,

although a great deal of help can be obtained from the instrument manufacturers who maintain sales staffs of engineers well versed in application problems. Manufacturers are also able to supply advice on a proper maintenance program, and also, generally, have factory instructions available for key personnel.

6. Continuous Process Development

Several years ago the J. T. Baker Chemical Company, manufacturers of five chemicals, anticipated the need for larger quantities of chemically pure (C.P.) carbon disulphide. The old process consisted of manufacturing crude carbon disulphide purifying it to technical grade and then purifying it further by means of a low production, time consumming, costly batch process. In line with their expansion program, it was necessary for the Baker people to increase production and lower the cost of chemically pure carbon disulphide. The most practical approach to this problem was the designing of a purification process which could, if necessary, convert their entire crude output to a chemically pure product in one operation.

Carbon disulphide is widely used as an industrial chemical in the manufacture of rayon, carbon tetrachloride, cellophane, dyes and as a solvent for rubber, phosphorus, fats and oils. Most of these processes operate successfully on the technical grade product which means there is no large

scale production of the chemically pure product. If this new process can turn out a pure product competitively priced with the technical grade, it should replace the technical grade product in industrial manufacturing.

To convert carbon disulphide from technical grade to chemically pure requires the removal of relatively small amounts of impurities, but involves considerable handling problems. Rather then develop a method of purifying carbon disulphide from technical grade to chemically pure, it was decided to employ a purification process which would receive crude and turn out a chemically pure product on a continuous basis.

Four years of investigation and experimentation were necessary to develop this process in the face of many difficulties. The process has been in operation since August 1948.

There are four main reasons why chemical manufacturers have been retarded in their efforts to employ such a process sooner. First, the cost of the process put the cost of the chemically pure product at a value which limited its wide industrial use. Second, only comparitively recently have adequate control devices been available for such a continuous process. Third, the process constitutes a radical change in the purification methods which have been employed for many years, meaning a new plant design and considerable expenditure. Fourth, the exceptionally explosive and corrosive hazards presented design problems which only comparitively new equipment has been able to solve. Carbon disulphide was the

cause of the explosion and damage to the Holland tunnel in May of 1949.

One of the outstanding factors in this new process is the fact that this process was designed for controllability since the plans included industrial controllers maintain the proper heat balance through out the process and insure a constant flow of product to and from the system, with minimum of heating and cooling. This type of control contributes to a minimum operating expense with higher yields and minimum disturbances in the process. Load changes of any variable are compensated for by the action of the various controllers. These factors combine to produce a sufficient quantity of chemically pure on a continuous basis to make the process economical. Complete plant operations are readily handled by one operator in the centrally located control room.

This process is one of the first that may be operated to produce comparitively large quantities of chemically pure carbon disulphide. The chemically pure product produced at this plant exceeds the American Chemical Society specifications for chemically pure carbon disulphide. The fact that all chemically pure products meet these standards, even with varying flow rates through the system, is a positive indication of the accurate and reliable control being obtained. Instruments are successfully operating with a hazardous product. They have prove-

ed themselves by acceptable performance on a new type of continuous process.

The fact that this process could not operate without automatic control instruments, clearly illustrates the industrial controllers influence design significantly and, therefore, should be seriously considered in any original plans.

CHAPTER V
CONCLUSIONS:

The use of control instruments as a means of increasing production, lowering steam and material costs, lowering labor costs, and increasing quality should be seriously considered by management in the process industries.

Control instruments have become a necessity in the research and development stages where processes are initiated; in production by making many processes economically possible, reducing labor costs, operating costs, increasing quality control by eliminating human errors; and in finance by providing increased production in existing equipment, extending the life of equipment, and lowering plant investment on new units.

It is managements duty to utilize modern devices such as modern control instruments to produce more efficiently. Instruments have proven their value in industries such as food, textile, chemical, metalurical, pharmaceutical, petroleum and paper.

Instruments have aided management in effecting cost reductions by increasing labor and equipment productivity and by a better utilization of raw materials.

By analyzing our present problems and effecting economies in these two directions we can take another step toward the realization of the free enterprise goal- the highest standard of living for the greatest number.

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